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By

Harold G. Bush and Tanchum Weller*

INTRODUCTION

Efforts to determine the mechanical properties of a material subjected to an inplane shear loading have resulted in the development of many techniques; each being characterized by certain advantages and disadvantages. These various methods are identified and discussed at length in the literature (see, for instance, references 1 and 2). Among the methods currently used is the "picture frame" technique.

The conventional picture frame technique of applying an inplane shear deformation to a material or structural specimen consists of applying a uniaxial force (usually tensile) at two diagonally opposite corners of a frame, or fixture, having very stiff members and which is attached to the edges of a square or rectangular specimen. The frame is pinned at all corners; therefore shear deformation of the specimen is not resisted by bending moments at the frame corners. Two major problems which plague this method are bending and extension of the frame members. Efforts to eliminate these deformations include both oversizing the edge member cross-section to minimize axial and bending deformations, and tapering these members to improve load transfer from the frame to the specimen. Neither method has proven to be a satisfactory solution. The purpose of this report is to present a new method for performing inplane shear tests which shows a marked improvement over the conventional, uniaxial picture frame technique.

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BIAXIAL SHEAR METHOD

The biaxial method for subjecting a test specimen to an inplane shear deformation is depicted in Figure 1, which shows a square sandwich specimen installed in a very stiff fixture with pinned corners. Frame deformations resulting from the conventional, uniaxial method of loading is depicted in figure 2a, where the edge members are shown to undergo both extension and bending. The biaxial method consists of simultaneously applying equal tensile and compressive forces along the frame diagonals through the corner pins. Figure 2b depicts the frame deformations resulting from this loading method, and indicates that it kinematically deforms into a parallelogram whose sides are unchanged in length. This type of frame deformation is required to subject the test specimen to a uniform shear strain. In the case of isotropic or orthotropic materials, this process is also equivalent to subjecting the specimen to a uniform shear stress. It is shown in figure 2b that the applied forces required with the biaxial method are one-half the magnitude required by the uniaxial method shown in figure 2a. This situation reduces the force transmitted locally, and consequently reduces local pin deformations. Static considerations show that the loading methods, given in figures 2a and 2b, result in applying the same shear load to the specimens.

EXPERIMENTAL INVESTIGATION

A shear test fixture incorporating the features of the biaxial method was designed and fabricated. The specimen configuration used is shown in Figure 3. Since composite materials are usually used as thin shells or plates, a sandwich configuration was selected to stabilize the thin flat laminates against shear buckling at a low value of load. The assembled test fixture and specimen is shown in Figure 4. The tensile load component is applied vertically by a standard tensile test machine. Attachment of the test machine to the fixture and specimen is by the pin and clevis arrangement shown in the figure. The compressive load component is applied horizontally by the hydraulic cylinder, load cell and tension bar arrangement also shown in Figure 4. The compressive load is measured by this load cell, while the tensile load is measured by a similar device built into the tensile test machine. Output from both load cells are recorded electronically. The pressure source for the compressive load component is an identical hydraulic cylinder installed in a compression test machine as shown by the insert in Figure 5. The compression test machine is calibrated with the load cell in the load path. The tensile and compressive load components are applied equally and simultaneously.

Extreme care is used to assemble the fixture and specimen in the test machine to insure uniform load transfer into the specimen by the loading frame. After the specimen is bonded together from the component parts, the outside surfaces of the steel doublers are ground flat and parallel. The specimen is then jig-drilled slightly undersize to fit the frame. Individual bolt holes are hand reamed for fit during final assembly into the frame. Bolts are torqued evenly around the frame periphery. After frame and specimen are assembled and torqued in such a manner that the corner pins remain free to rotate, the loading apparatus is assembled on the frame.

Uniaxial and Biaxial Comparison

To quantify the difference between uniaxial and biaxial loading of the shear frame, four identical aluminum faced sandwich specimens with aluminum honeycomb core were fabricated and instrumented with strain gages. Three of the sandwich specimens were tested uniaxially to failure. The fourth specimen was initially tested uniaxially in the elastic range and subsequently tested biaxially to failure. Results of these tests are shown in Figure 6 where the average value of the principal tensile to compressive strain ratio $|\varepsilon_t/\varepsilon_c|$ over the specimen face is plotted as a function of total applied load. A specimen subjected to a uniform shearing deformation will exhibit principal tensile and compressive strains which are equal in magnitude. The ratio of these strain components indicates how well a shear frame applies a uniform shear deformation to a specimen. An envelope of the experimental results for the uniaxial tests of three specimens is shown as the cross-hatched area in Figure 6. It is shown that these specimens did not exhibit a uniform shear deformation, either in the elastic or inelastic range. The fourth specimen (circles in Figure 6) showed similar behavior when tested uniaxially in the elastic range as indicated by the circles in the cross-hatch area. However, when the same specimen was tested biaxially to failure, a uniform shearing deformation was achieved in both the elastic and inelastic regions as shown in Figure 6 (circles along $|\epsilon_t/\epsilon_c| = 1$). The frame was also instrumented with strain gages which verified that using the biaxial loading technique, both extension and bending of the edge members was essentially eliminated. These tests show that the biaxial method of loading a shear frame subjects a specimen to a much more uniform shear deformation, than does the uniaxial method.

Frame Friction Tests

Two aluminum plate specimens, having the same planform configuration as shown in Figure 3, were fabricated and tested to determine if any frictional effects were present in the assembled shear frame and loading apparatus to cause errors in the experimental results. Experimentally measuring the shear modulus of a known, well characterized material such as aluminum, will expose any friction which is present. The results of two aluminum plate tests are shown in Figure 7 as the solid curve. Both tests yielded identical results for the shear modulus of aluminum which was calculated by the following method. The shear stress ,τ, is given by the relation

$$\tau = \frac{P}{\sqrt{2}\, at} \qquad (1)$$

where $P = |P_{tension}| + |P_{compression}|$

a = Shear specimen depth

t = Total membrane thickness

The shear modulus, G, is calculated from the relation

$$G = \frac{\tau}{\gamma} = \frac{P}{\sqrt{2}\, at\gamma} \qquad (2)$$

where γ = shear strain = $|\varepsilon_t|+|\varepsilon_c|$

Using the aluminum plate response shown in Figure 7, the elastic shear modulus was calculated to be approximately 27.6 GPa which is equal to the value given in reference 3. Thus, it may be concluded that frictional effects are negligible.

Core Stiffness Tests

Honeycomb core, unattached to face sheets, does ot have any significant shear stiffness in a plane parallel to the facings. However, when bonded to face sheets, honeycomb core becomes an integral part of the structural assembly and can provide additional stiffness in the plane of the sandwich which is normally not considered. In the case of test specimens used to measure material properties it is necessary to consider all effects which may be present in the experiment. Considering a sandwich panel subjected to an inplane shear load, it may be written that

$$N_{sand} = N_{faces} + N_{core} \quad (3)$$

The shear load can be expressed as

$$N = Gt\gamma \quad (4)$$

and equation 3 becomes

$$(Gt\gamma)_{sand} = (Gt\gamma)_{core} + (Gt\gamma)_{faces} \quad (5)$$

Assuming that inplane shear deformations of the faces and core are equal results in

$$\gamma_{sand} = \gamma_{core} = \gamma_{faces} \quad (6)$$

Therefore, equation (5) becomes

$$(Gt)_{sand} = (Gt)_{core} + (Gt)_{faces} \tag{7}$$

The shear stiffness of the sandwich may be determined experimentally, and is given from equation 2 as

$$(Gt)_{sand} = \frac{P}{\sqrt{2}\, a\gamma} \tag{8}$$

Using a known material for the facing (such as aluminum) determines $(Gt)_{faces}$ in equation (7). Therefore, the shear stiffness of the core material is given by

$$(Gt)_{core} = \frac{P}{\sqrt{2}\, a\gamma} - (Gt)_{faces} \tag{9}$$

Two aluminum faced sandwich specimens were fabricated as shown in Figure 3. The experimental stress-strain results obtained from tests of these sandwich specimens are also shown in Figure 7 as a dashed line. The difference in slope between the sandwich and plate results shown in Figure 7 is a measure of the stiffening effect of the aluminum honeycomb core in the plane of the faces. Using equation (9), the apparent inplane shear modulus of honeycomb core, in the elastic range, is found to be

$$G_{core} \simeq 0.21 \text{ GPa } (30{,}000 \text{ psi}) \tag{10}$$

for 5056 Al/Hc (Density = 91.3 kg/m^3).
Thus, for specimens having the same honeycomb core material this value of core modulus can be used to reduce the inplane stiffness measured during shear tests of those specimens.

Graphite-Epoxy Tests

Stress concentrations that exist at the specimen corners (see Figure 8) must be considered when testing high strength, filament reinforced composite materials. The polymeric matrix materials normally used in such high strength materials do not display any significant ductility. Rather, the matrix appears to behave in a brittle fashion. Therefore, stress concentrations in such materials are apt to precipitate failure at load levels less than the material ultimate stress.

Ten graphite-epoxy (Thornel 300/Narmco 5208) sandwich specimens with 8 ply faces were fabricated. The faces were $(45,-45)_{2S}$ laminates because this configuration has the highest shear stiffness and strength. Five specimens were tested as fabricated and five were tested with titanium doublers (.86 mm thick) bonded into the facing corners as shown in Figure 8. These small doublers were local reinforcement to reduce the high tensile strains (ε_t) shown in the figure. Shear stress-strain results for these tests are shown in Figure 9. For simplicity the core effects were initially neglected. The average shear modulus for the five reinforced and five unreinforced specimens were found to be essentially the same (as noted on the figure). Therefore, the corner doublers did not have any apparent stiffening effect on the specimen. The average modulus for all ten specimens is shown in Figure 9 to be 35.7 GPa (neglecting core effects). Using equation 9, which considers the stiffening effect of the aluminum honeycomb core, the correct shear modulus of the faces was found to be 33.4 GPa. Thus, neglecting the core stiffness resulted in calculating a shear modulus which was approximately 7% high. If the facings were less stiff (i.e. unidirectional material) the error would be even larger.

The average ultimate shear strain from tests of the five specimens with corner doublers was found to be .01088 which was 22% higher than the unreinforced specimens. Using this more correct value of ultimate shear strain, and the corrected shear modulus previously calculated, the average ultimate strength of the (±45)Gr/E (T300/5208) laminate is found to be 363 MPa.

Strain Gage Surveys

During the aluminum and ±45° Gr/E shear tests described previously, the specimen faces were heavily instrumented with strain gages which verified the uniformity of shear strain over the majority of specimen surface. However, it was observed that a reduced strain zone (shown in Figure 10) exists along the specimen diagonals and was apparently caused by the corner cutouts. Principal extensional strains (denoted by ε_t and ε_c) parallel to the diagonals in this region were found to be reduced approximately 3% for the aluminum specimens and up to 10% for the ±45° Gr/E specimens. Considering the panel center where the diagonal zones cross, both principal strain components are reduced by these magnitudes. Thus, shearing strain calculated from the principal strain components measured along the diagonals or at the panel center, would be smaller than the actual magnitude. The ±45° composite laminate is the worst case, having filaments which run along the diagonals between free edges of the corner cutouts. Extensional strains of these filaments are induced by matrix shear, therefore, these strain components lag those outside this zone. Other laminate configurations were tested (reference 5) which contained angle ply laminae. The reduced strain zone did not occur for any laminate except the ±45° configuration. The preferred locations for making principal strain measurements on any specimen is at the center of the facing quadrants as shown in Figure 10. In order to insure measurement of overall material behavior, and not a local response, it is highly recommended that the average principal strain measurements over both faces of the material specimen be used to compute the shear stress-strain response of a material specimen.

THEORETICAL CONSIDERATIONS

The biaxial method of testing for inplane shear properties of a material described herein, subjects the specimen to a uniform shear strain instead of a uniform shear stress. If the material is isotropic or orthotropic, the uniform shear strain method is the same analytically as the uniform shear stress method. If the material is highly anisotropic (eg; exhibits high membrane extension-shear coupling) the uniform shear strain method can differ appreciably from the uniform shear stress methods. The anisotropic membrane constitutive relations are (from reference 4)

$$\begin{bmatrix} N_x \\ N_y \\ N_{xy} \end{bmatrix} = \begin{bmatrix} A_{11} & A_{12} & A_{16} \\ A_{12} & A_{22} & A_{26} \\ A_{16} & A_{26} & A_{66} \end{bmatrix} \begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} \tag{11}$$

Equations (11) can be written in compliance form as

$$\begin{bmatrix} \varepsilon_x \\ \varepsilon_y \\ \gamma_{xy} \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} & S_{16} \\ S_{12} & S_{22} & S_{26} \\ S_{16} & S_{26} & S_{66} \end{bmatrix} \begin{bmatrix} N_x \\ N_y \\ N_{xy} \end{bmatrix} \tag{12}$$

where the compliances (S) are, in terms of the membrane stiffnesses (A) are

$$\begin{aligned} S_{11} &= (A_{22}A_{66} - A_{26}^2)/\Delta \\ S_{12} &= (A_{16}A_{26} - A_{12}A_{66})/\Delta \\ S_{22} &= (A_{11}A_{66} - A_{16}^2)/\Delta \\ S_{16} &= (A_{12}A_{26} - A_{16}A_{22})/\Delta \\ S_{26} &= (A_{12}A_{16} - A_{26}A_{11})/\Delta \\ S_{66} &= (A_{11}A_{22} - A_{12}^2)/\Delta \end{aligned} \tag{13}$$

where $\Delta = (A_{11}A_{22} - A_{12}^2)A_{66} - A_{11}A_{26}^2 + 2A_{12}A_{\cdot\cdot} \ldots \quad A_{22}A_{16}^2$

Assuming $N_x = N_y = 0$, the laminate inplane shear stiffness for the uniform shear stress case may be derived from equations (11) and is given by

$$(G_{xy}t)_{Stress} = A_{66} - \frac{A_{16}(A_{16}A_{22} - A_{12}A_{26}) + A_{26}(A_{26}A_{11} - A_{12}A_{16})}{A_{22}A_{11} - A_{12}^2} \qquad (14)$$

Assuming $\varepsilon_x = \varepsilon_y = 0$, the laminate inplane shear stiffness for the uniform shear strain case may be derived from equations (12) and is given by

$$(G_{xy}t)_{Strain} = \frac{1}{S_{66} - \frac{S_{16}(S_{16}S_{22} - S_{12}S_{26}) + S_{26}(S_{26}S_{11} - S_{12}S_{16})}{S_{11}S_{22} - S_{12}^2}} \qquad (15)$$

In the case of isotropic and orthotropic laminates (eg: $A_{16} = A_{26} = 0$), equations (14) and (15) are equivalent. When using the biaxial method to test laminates which display inplane anisotropy (such as required for aeroelastic tailoring of aircraft wings), equation (15) is the more correct theoretical laminate shear stiffness relation to use instead of equation 14. Using test methods such as rail shear (ref. 2) where the boundary conditions are mixed or undefined, it is unclear which relation is more appropriate. Anisotropic materials, subjected to a uniform shear strain actually are loaded in a combined membrane state where N_x and N_y are not equal to zero. In fact, due to the interaction between extension and shear, and the resultant involvement of the specimen boundary conditions, it may be impossible to accurately test anisotropic laminates in shear except in a full scale test which reproduces the boundary stiffnesses and loading of the real structure.

CONCLUDING REMARKS

A new technique for experimentally obtaining the inplane shear properties of materials has been developed and presented in this report. This technique - the biaxial method - has been examined experimentally and shown to apply a shearing deformation more uniformly to orthotropic and isotropic material specimens than the previously used uniaxial picture frame technique. Furthermore, experimental efforts have been presented which examine those performance characteristics which are peculiar to the test method or specimen.

The stiffening effect of honeycomb core on the inplane shear response of a sandwich panel has been identified, and an appropriate method for considering this effect has been presented.

The effect of stress concentrations in the specimen corners has been presented. One technique for reducing this effect - bonding on localized doublers - prevents "premature" material failure without detectable stiffening of the test specimen.

Some considerations of subjecting a material to a uniform shear strain instead of a uniform shear stress have been presented. The theoretical laminate shear stiffness relations, with which experimental performance should be compared, have been presented for both the shear stress and shear strain cases. Some problems of testing anisotropic (i.e. - extension and shear coupling present) materials in shear have been reviewed. The necessity for using the uniform shear strain laminate stiffness relation in conjunction with the biaxial method for prediction of experimental performance of anisotropic materials has been discussed.

An experimental investigation of the biaxial method for inplane shear testing of materials has been presented and discussed. Results presented in this report and experience to date at Langley Research Center show this to be a useful and accurate test technique for obtaining the properties of materials subjected to inplane shear deformation.

REFERENCES

1. Composite Materials: Testing and Design, ASTM STP 460, American Society for Testing and Materials, 1969.

2. Jones, R. M.: Mechanics of Composite Materials. Scripta Book Company, Washington, D. C., 1975.

3. Military Standardization Handbook; Metallic Materials and Elements for Aerospace Vehicle Structures. Mil-HDBK-5B, Volume 1, September, 1971.

4. Ashton, J. E.; Halpin, J. C.; and Petit, P. H.: Primer on Composite Materials: Analysis. Technomic Publishing Co., 1969.

5. Weller, T.: Experimental Studies of Graphite-Epoxy and Boron-Epoxy Angle Ply Laminates in Shear, NASA CR-14523[illegible], 1977.

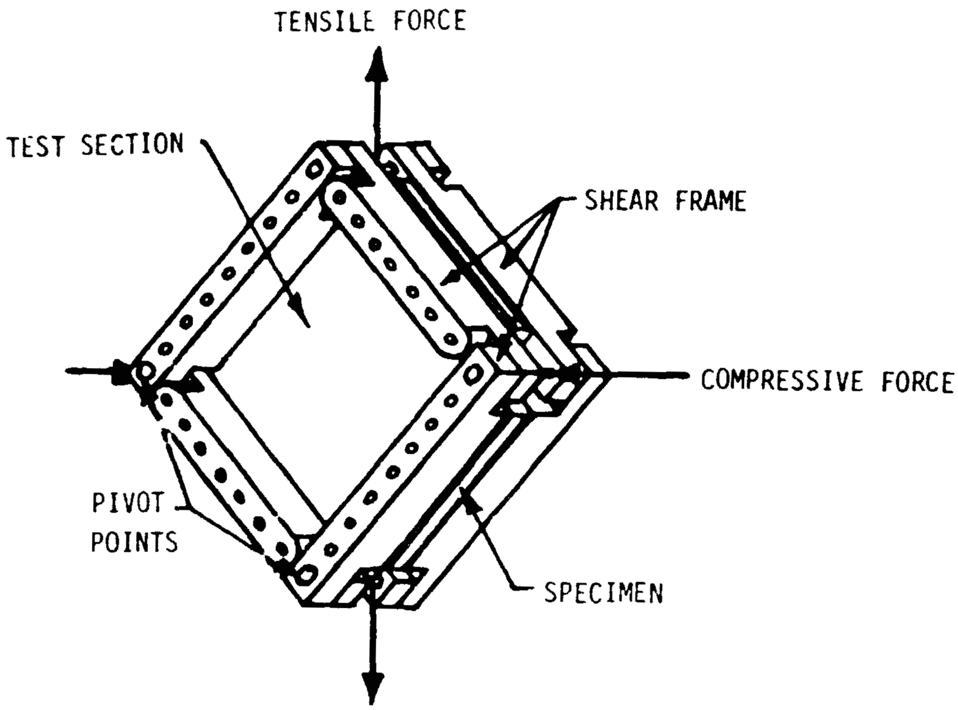
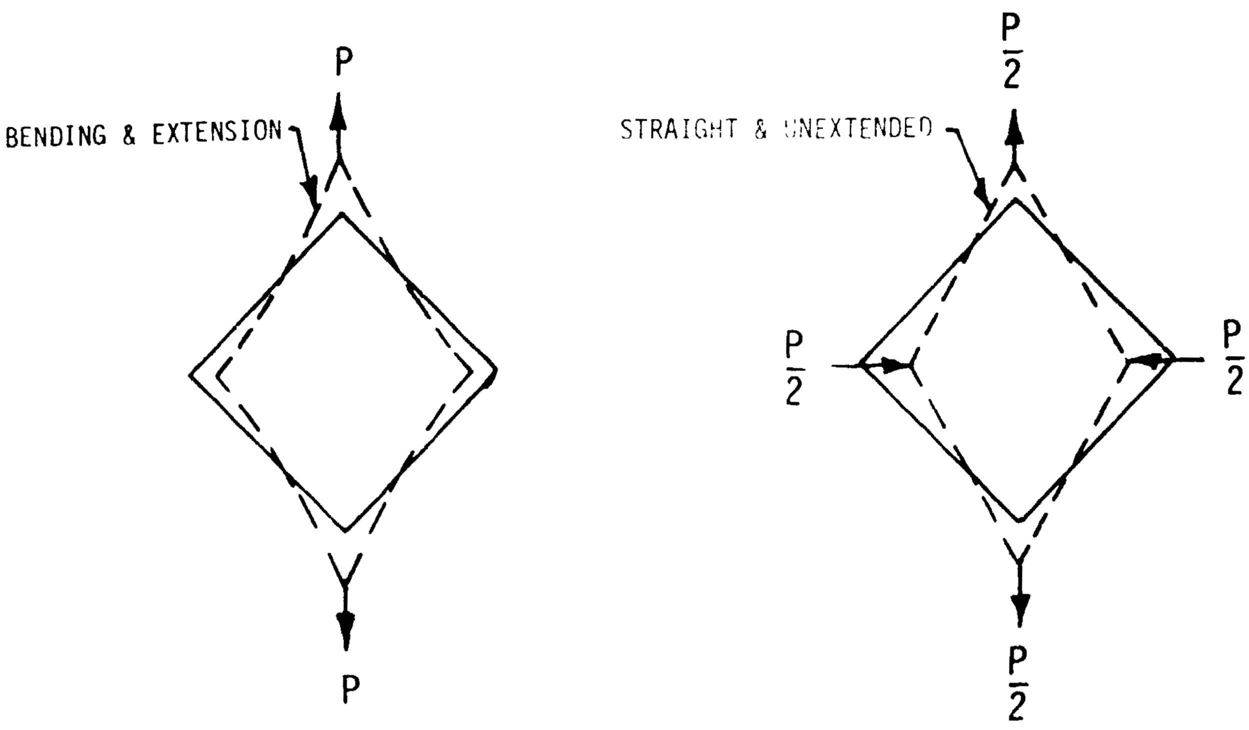


Figure 1.- Sketch of biaxial shear frame and specimen



(a) Uniaxial method

(b) Biaxial method

Figure 2.- Schematic of shear frame deformations

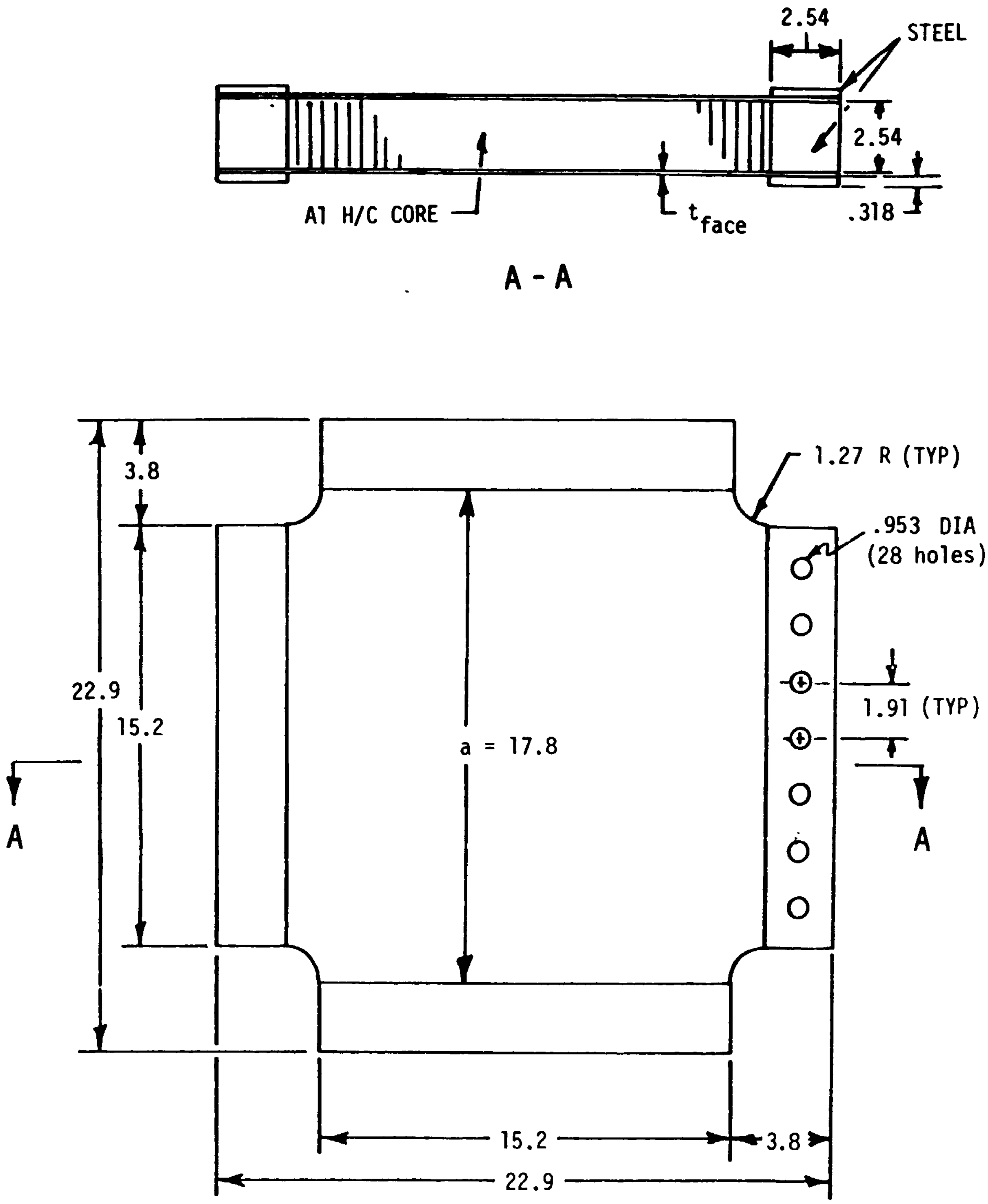
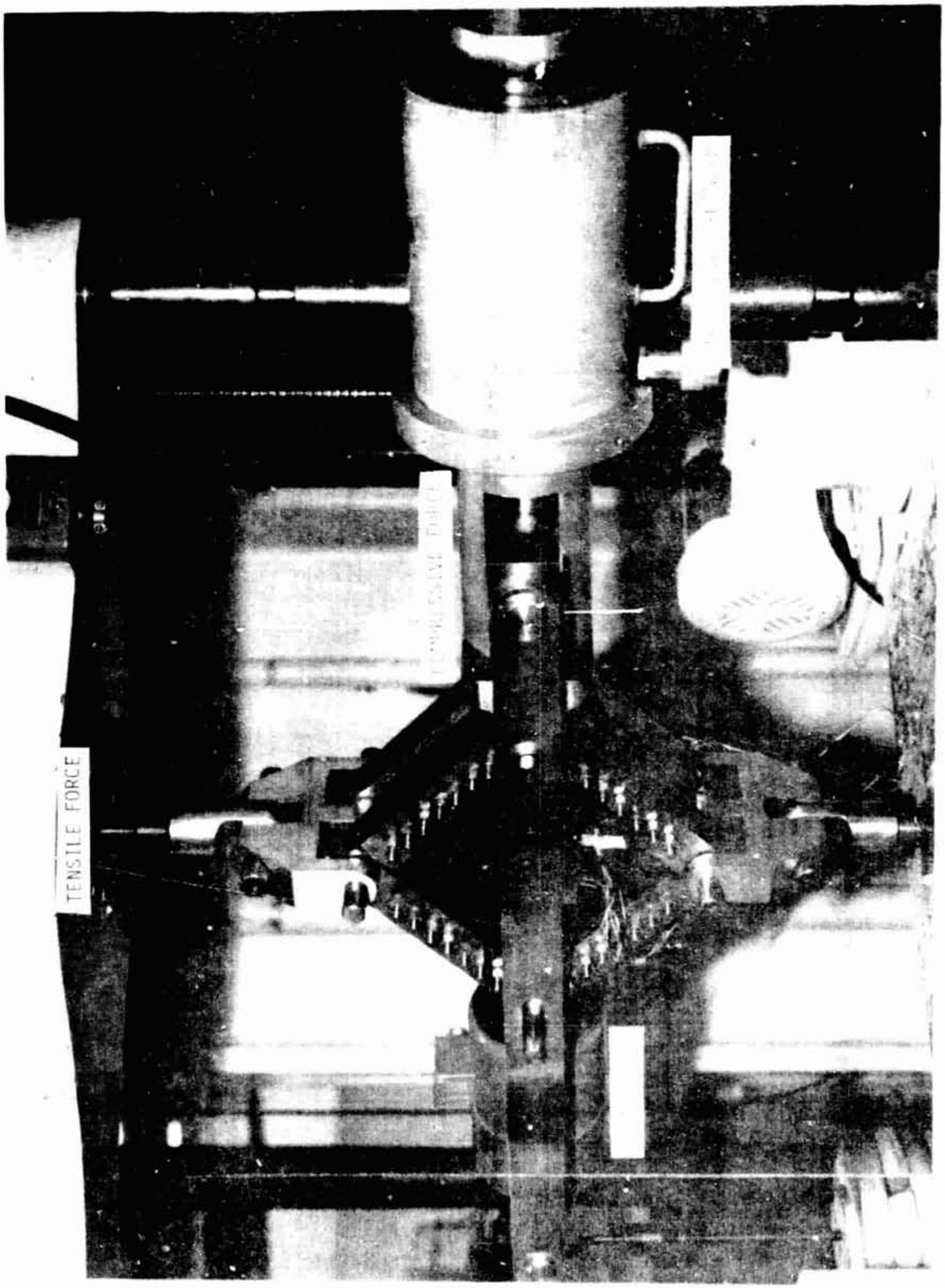


Figure 3.- Shear test specimen configuration (dimensions in cm)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TENSILE FORCE

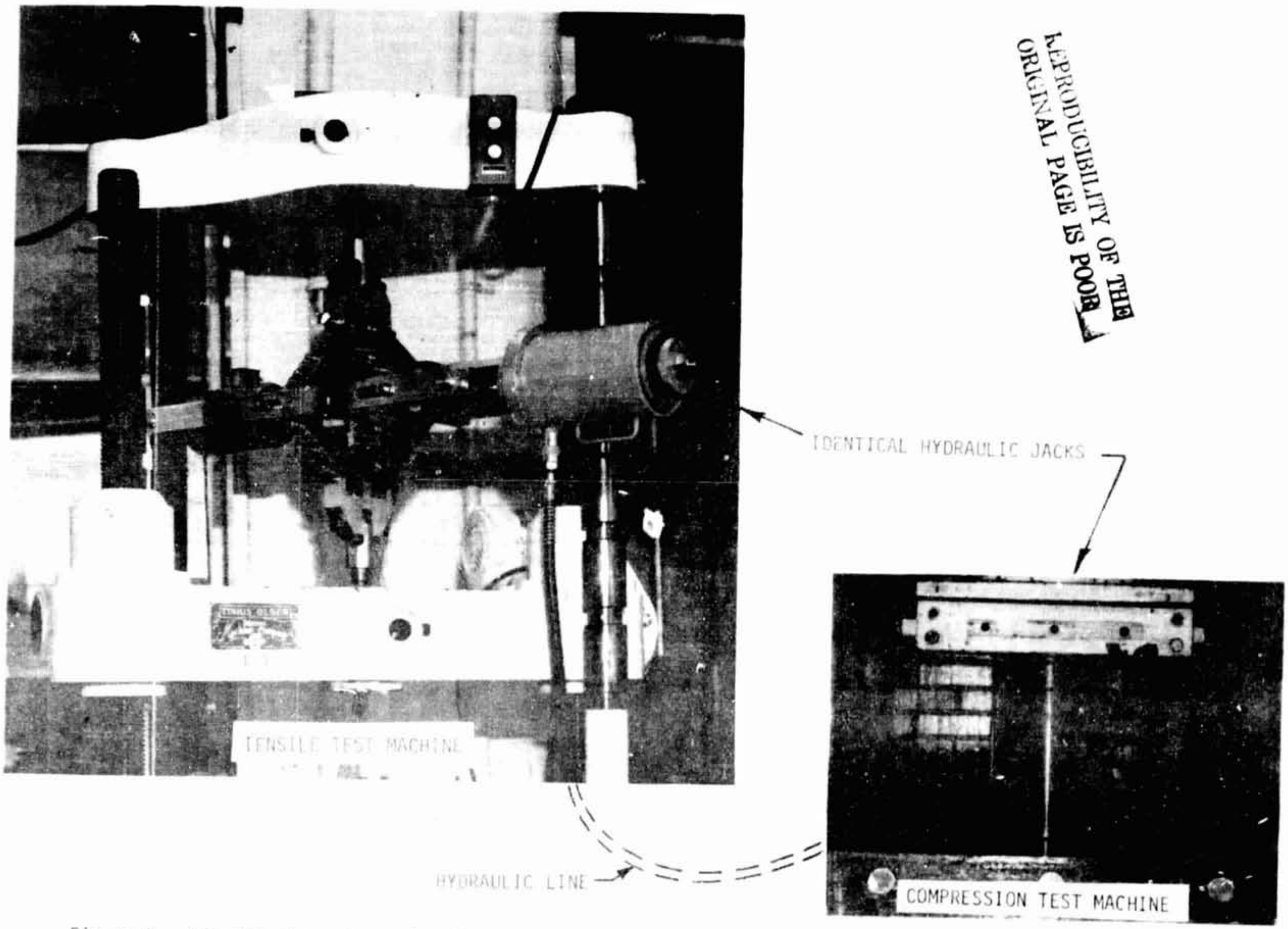

Figure 5.- Biaxial shear frame loading method

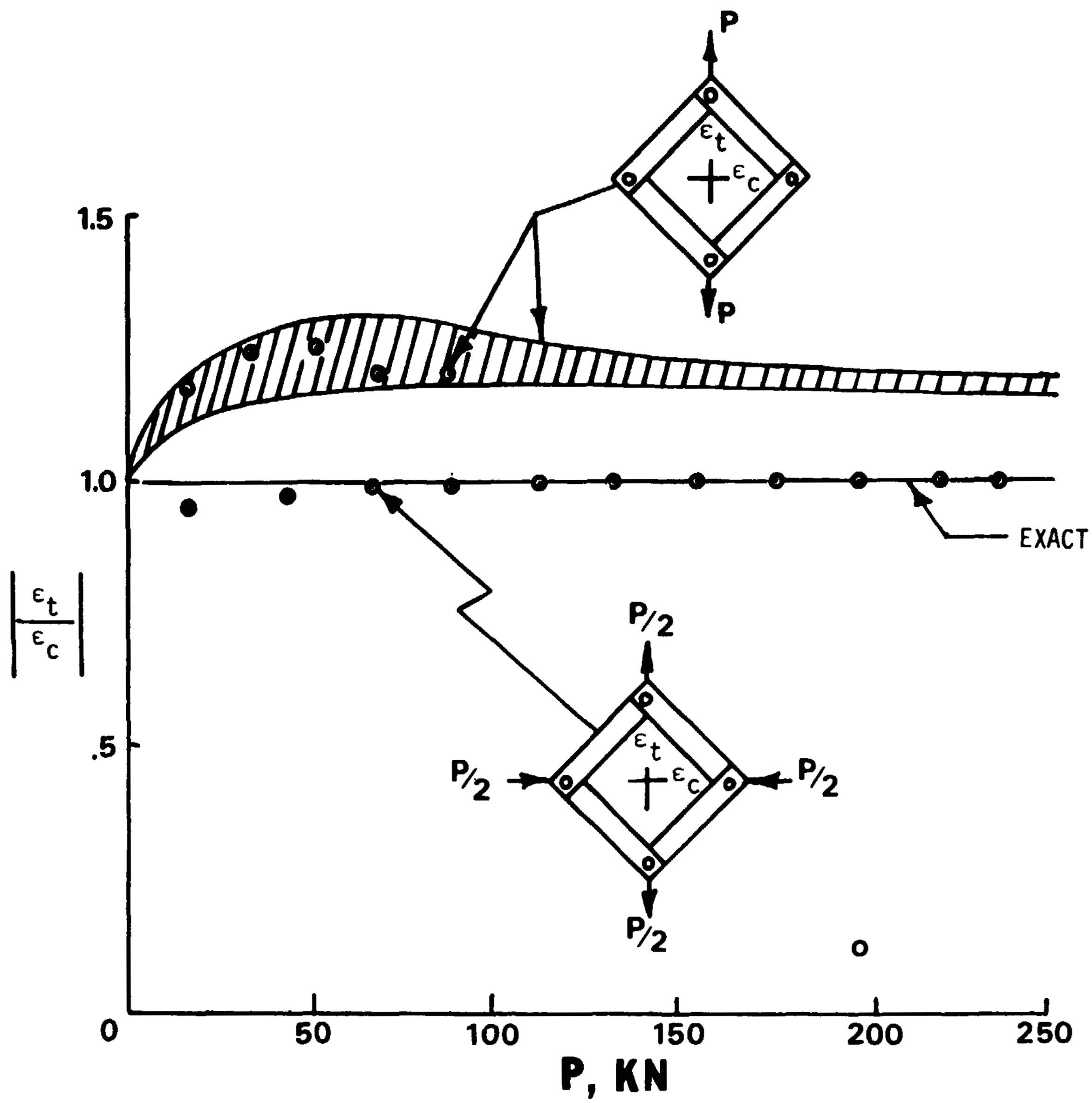

Figure 6.- Principal strain ratio comparison for uniaxial and biaxial inplane shear tests

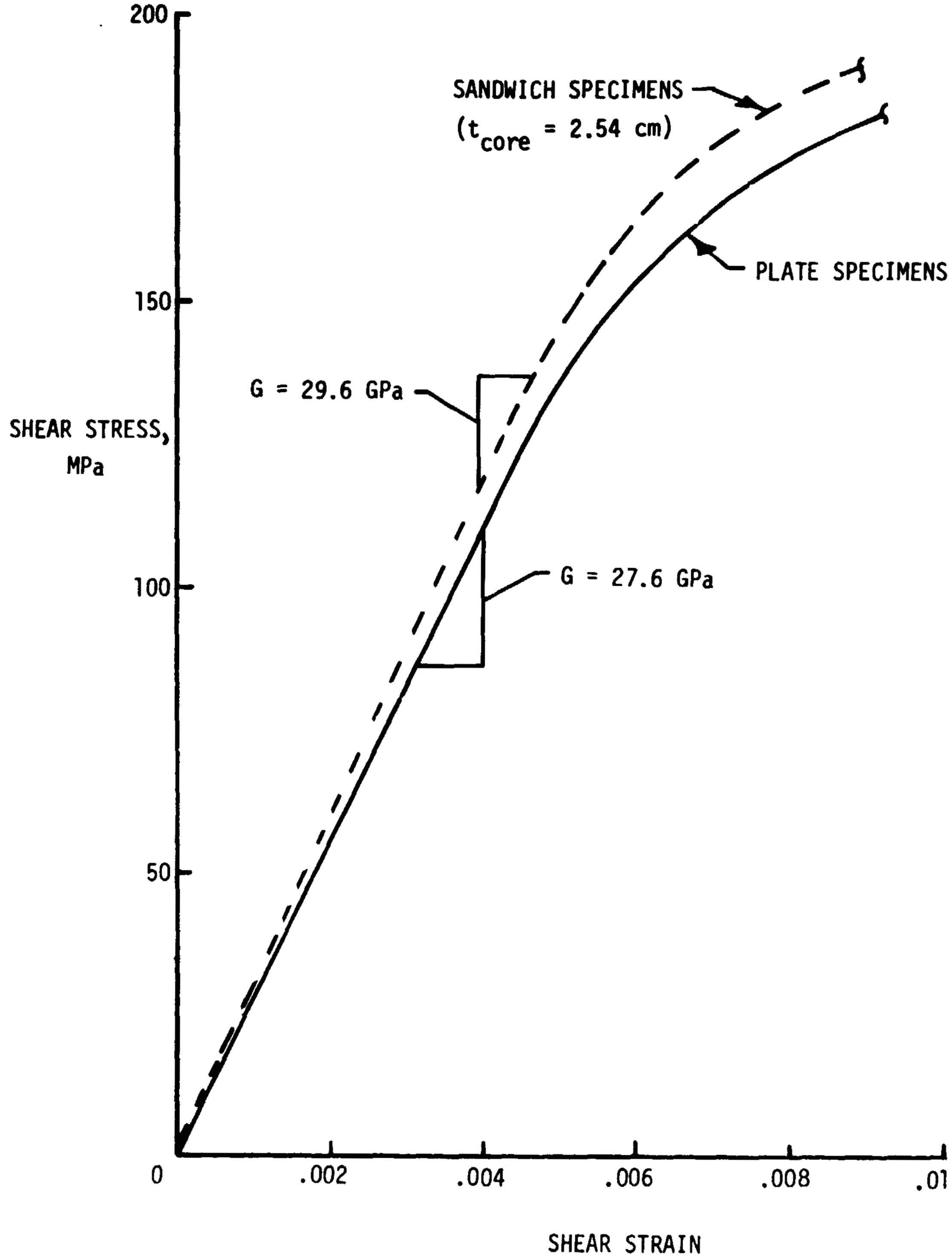

Figure 7.- Comparison of aluminum plate and sandwich inplane shear test results

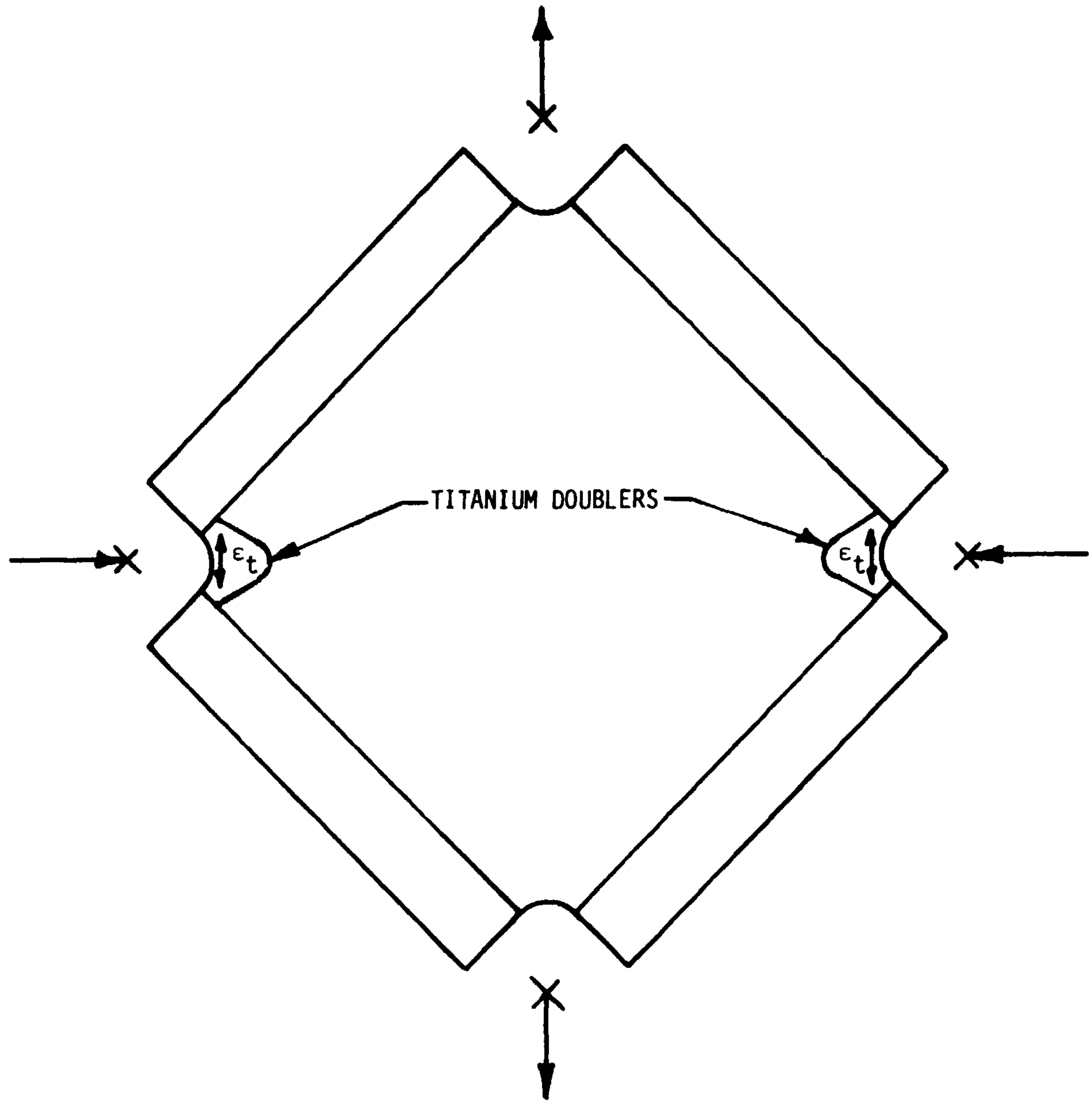

Figure 8.- Location of titanium doublers to reduce corner stress concentrations

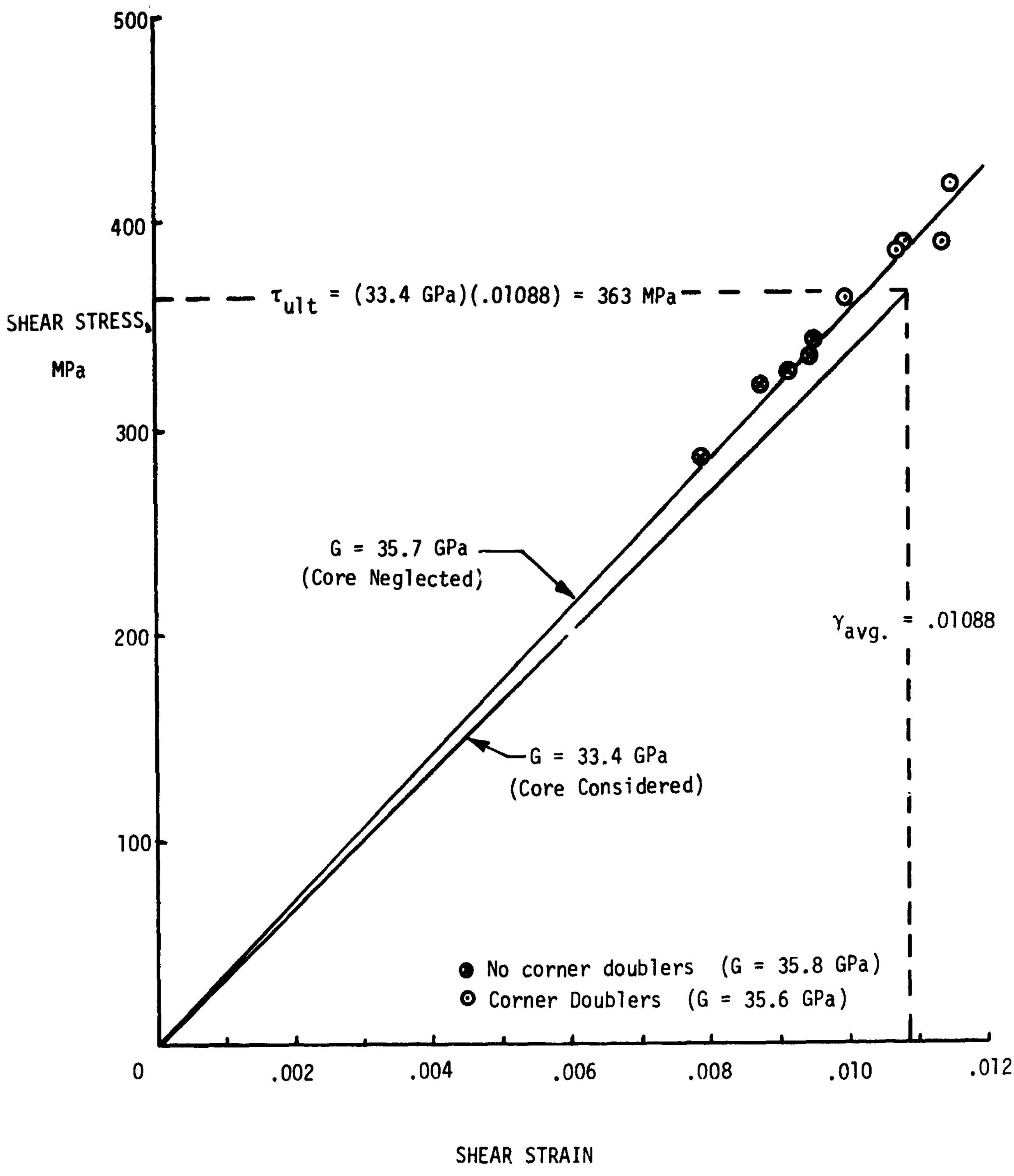

Figure 9.- Shear stress-strain response of (±45) graphite-epoxy (T300/NARMCO 5208)

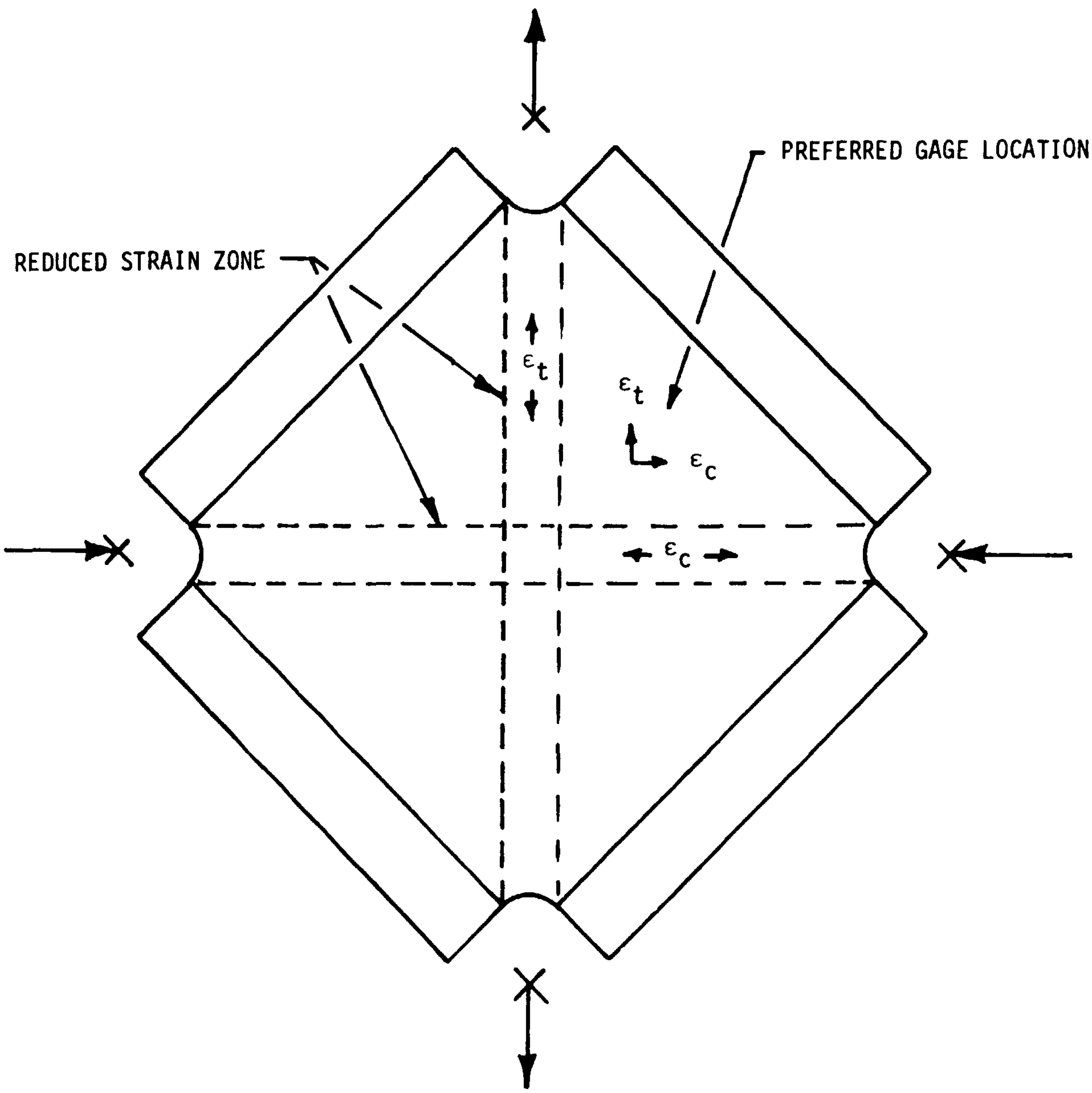

Figure 10.- Schematic of reduced strain region in (±45) composite laminates

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15 Supplementary Notes

16 Abstract

This report describes a new technique - the biaxial method - for performing inplane shear tests of materials using a shear frame. An experimental investigation of this method is presented. Aluminum plate and sandwich specimens were used to characterize the uniformity of shear strain imparted by the biaxial method of loading as opposed to the uniaxial method. The inplane stiffening effect of aluminum honeycomb core was determined. Test results for (±45) graphite-epoxy laminate are presented. Also some theoretical considerations of subjecting an anisotropic material to a uniform shear deformation are discussed.

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